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A COMMERCIAL TEST OF RHEOSTATS

by

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and

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A Thesis Submitted for the Degree of

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A COMMERCIAL TEST OF RHEOSTATS.

The test is almost exclusively one to determine the efficiency in operation of the rheostats now on the market. Consequently, purely theoretical subjects, such as best arrangement of plates for heat dissipation, etc., will receive very little attention.

The literature upon the subject is very meagre, and the largest part of the information was derived from careful perusal of manufacturers' catalogues. The following references include only those articles of importance and whose length is over a column of the ordinary technical paper.

R E F E R E N C E S.

Metallic Resistances, by Kilburn Scott, in Lond. Elec. Rev. July 15, 1898.

Construction and Calculations for Rheostats by P. M. Heldt in Am. Elec., March, 1897.

Liquid Rheostats by H. S. Webb in Am. Elec., February, 1898.

Rating of Resistance Spirals by V. Zingler in Lond.

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Elec. Rev., September 24, 1897.

Starting Resistances by E. A. Pochin in London Elect. May 7, 1897.

Design and construction of Rheostats by the Editor of Elec. Ind., November, 1895.

Rheostat Insulation in Elec. World, Vol XXIII, p. 480.

Some Facts Regarding Wire for Resistance Coils by W. A. Anthony in Elec. World, Vol. X, p. 338.

Motor Rheostats by H. Ward Leonard, in Elec. World, Vol. XXVI, p. 624.

The Regulation and Protection of Electric Motors by H. H. Cutler in Elec. World, April 16, 1898.

The following pages are devoted to a general discussion, followed by a synopsis of our work.

A rheostat is a device for controlling the current in an electrical conductor by inserting or withdrawing resistance from the circuit closed by the conductor and the rheostat. Any change of current caused by the use of resistance must necessarily be accompanied by a gain or loss of energy which is dissipated in the resistance in accordance with the well-known formula C^2R = Watts lost in heat.

The principal parts of a rheostat are, the resistance material, the insulators and supports for the resistance, the

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materials to conduct off the heat from the resistance to those parts of larger area and which are more exposed to the air, and the frame, upon the face of which, ordinarily, the contact terminals as well as the safety appliances are placed.

The problem in the design of a rheostat is to make it so as to be unaffected by expansion strains, to be arranged for the best dissipation of heat, to be compact in form, and to present a workmanlike, if not a handsome appearance. In some cases two more conditions have weight, viz.: protection from moisture in the air and from acid fumes.

The substances used for resistance are very numerous. Those most commonly used may be divided into two classes; liquid and metallic or solid conductors. Liquid rheostats have a very limited application because of general unwieldiness, variability in action and difficulty of making connections on switchboard from the rheostat. They are now sometimes used as a shunt around a large switch. After the switch is pulled, the rheostat is worked from closed plates to maximum distance apart and then one plate lifted out, breaking the circuit entirely. This method serves to protect the contacts of the large switch and often answers better than auxiliary contacts of carbon, which are more frequently used. The liquids most commonly used are solutions of salt, zinc

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sulphate, sulphuric acid and soda. The most common form of liquid rheostat consists of a brine barrel with plates of iron inserted at the edges. These rheostats evidently work better with alternating than with direct currents, because there is no appreciable electrolytic action to throw up scum and thus decrease the radiating surface in the case of the former. As evaporation is a very powerful cooling agent, liquid rheostats have an enormous current capacity, but this is best not utilized on account of vigorous boiling of the solution.

The second class includes a number of substances, the materials most commonly used being copper, lead, iron and carbon. Metals used in alloys are nickel, tin, zinc, manganese, platinum, and silver. The last two metals are not used in alloys for commercial work on account of their prohibitive cost. Copper is very rarely used pure because of its low resistance, its use being practically limited to large electrolytic refineries. Lead is barely used at all for obvious reasons, as it is very heavy and fuses easily. Iron is very largely used at present and is coming more into use every day. Carbon is used mostly for what might be termed "homemade" rheostats, although carbon has innumerable valuable uses as a resistance. Of the alloys, German silver is most used, its common composition being .60 copper, .25 zinc and .15 nickel. We rarely

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meet with rheostats which have resistance material other than iron or German silver.

Kilburn Scott, in London Elec. Review, gives the range of wire sizes used for resistance as from #24B. W. G. to #8 B. W. G. The two limits are fixed on account of mechanical strength and difficulty of winding respectively. However, #24 B. W. G. can hardly be considered a limit, as with proper supporting devices wires as small as #36 B. & S. have been successfully used.

In the same article, Zingler gives some interesting data regarding resistance spirals. His requirements were terse, but comprehensive, they being:

(1) Proper mechanical strength when fixed, so as to withstand vibration and resist sagging.

(2) Physical qualifications to absorb a certain number of watts without undue heating.

The coils he used were wound close upon a mandrel, and were then taken off and stretched to twice their length. He considered that this gave the best elasticity, and that the pitch was best for a mean between space occupied by the spiral and the best value for heat dissipation. The coils were set vertical. For platinoid wire he gives the following table:

Size of Wire	Diameter of Mandrel.
10, 11, 12	7/8"

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13, 14	7/8" or 3/4"
15, 16	3/4" or 1/2"
18, 19	1/2"
19	3/8"

His method of testing was to pass a current through the coil while he held a small strip of linen paper around a portion of the spiral. The current was increased until the paper turned a light yellow. The experiments were repeated with galvanized steel wire with the same results as with the platinoids. Below is a table of tests of the latter:

Mandrel.	Watts Required to Turn Paper Yellow.
7/8" Stretched.	50
3/4" "	40
1/2" "	30
3/8" "	20

When resistance spirals are used for traction purposes, the coils have to be supported in order to prevent vibration. This is generally accomplished by winding them upon an asbestos tube, although they have been wound and slipped into a thin tube of asbestos. With these methods of winding the question of mechanical strength of the spirals practically vanishes. Due allowance has to be made for mutual heating of coils and careful provision made for the vertical circulation of the air. The top of the spirals will thus become the hottest, due to the convection of the air.

The following table (Table A) is given by Zingler for galvanized steel spirals in air, without other support than

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TABLE A.

S. W. G.	Internal Diameter Of Spiral	Resistance Per Foot of Spiral Cold	SPIRAL Pounds per Foot of Spiral	Turns per Foot	100 WATTS PER FT. Res.	P. D.	Amp.
8	7/8"	.028	.67	34	.05	2.25	45
9	7/8"	.055	.63	41	.08	3	37
11	7/8"	.067	.53	50	.115	3.5	36.5
14	7/8"	.194	.26	55	.372	6.1	16.4
15	7/8"	.350	.25	50	.55	7.25	13
18	7/8"	.501	.11	48	.865	9.5	11
14	7/8"	.151	.19	60	.29	5.5	18.9
15	1/2"	.204	.16	60	.38	6.25	16.4
17	1/2"	.252	.12	60	.51	7.25	14

200 WATTS PER FT. Res.	P. D.	Amp.	300 WATTS PER FT. Res.	P. D.	Amp.
.055	3.3	61	.06	4.25	75
.095	4.5	45	.11	5.75	52
.145	5.5	37	.17	7.25	42
.458	9.33	20.37	.53	12.60	23.7
.68	11.75	17.3	.78	15.25	19.5
1.12	15.	13.4	1.39	20.25	14.6
.38	8.75	23	.45	11.75	26
.5	10	20	.61	13.5	22
.67	11.75	17.5	.83	15.75	19

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top and bottom connections.

Table B is a comparative table taken from Kilburn Scott in an article in the London Elec. Review. He states that "Manganim", a substance of composition of about 12% Mn, 2% Ni and 86% Cu has the lowest temperature coefficient. An alloy known as "Constantin", of composition 40% Ni and 60% Cu was favorably commented upon by several journals. "Manganin" oxidizes at 100° C, but with a good coat of varnish the temperature may be raised without injury. "Constantin", as can be seen from its composition, is a very non-oxidizable alloy and it is claimed that 300° C can be easily withstood.

The iron wire, the result of whose tests are recorded in Table B was best galvanized charcoal iron. It probably corresponds to E. B. or E. B. B. galvanized wire on the common market, as the analyses indicate. The columns headed "Normal Current in the Iron Frame" may be taken as approximately the safe current for continuous use when the wire is wound into a spiral and suspended vertically in the air. The column headed "Amperes for One Minute" gives the values of currents under the same conditions except that of time. He states that the diameter of mandrels were taken from practice, by which we infer he meant his practice rather than the average practice, but his sizes correspond closely to those of Zingler

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HEADINGS FOR TABLE "B".

Column

1	B. W. G.
2	Diameter in inches.
3	Approximate weights in pounds per yard at .31 pounds per cubic inch.
4	Approximate watt dissipation per yard for a rise of 500 C with normal current.
5	Diameter in inches of mandrel on which wire is coiled.
6	Length in inches of spiral of 100 turns, close coiled.
7	" " " " " " 100 " equally spaced.
8	Length in yards of wire in coil of 100 turns, close coiled.
9	Resistance ohms per yard. German silver. Amperes carried.
10	Normal current in iron frame. German silver. Amperes carried.
11	German silver. Amperes carried. For one minute.
12	Platinoid. Resistance ohms per yard.
13	Platinoid. Amperes carried. Normal current in iron frame.
14	Platinoid. Amperes carried. For one minute.
15	Iron (Galvanized). Resistance ohms per yard.
16	Iron (Galvanized). Amperes carried. Normal current in iron frame.
17	Iron (Galvanized). Amperes carried for one minute.
18	Manganin. Resistance ohms per yard.
19	Manganin. Amperes carried. Normal current in iron frame.
20	Manganin. Amperes carried. For one minute.

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TABLE "B".

1	2	3	4	5	6	7	8	9	10	11
26	.018	.003	.5	.375	1.8	3.6	3.37	1.39	.5	1
25	.020	.0035	.75	.375	2	4	3.42	1.12	.75	1.5
24	.022	.004	.875	.375	2.2	4.4	3.46	.871	1	2
23	.025	.005	1.	.375	2.5	5.	3.48	.675	1.25	2.5
22	.028	.007	1.25	.375	2.8	5.6	3.50	.539	1.5	3.
21	.032	.009	1.375	.375	3.2	6.4	3.55	.410	1.75	3.5
20	.035	.0108	1.5	.5	3.5	7	4.66	.345	2.25	4.5
19	.042	.0148	1.75	.5	4.2	8.4	4.74	.241	2.5	5.
18	.049	.021	2.	.5	4.9	9.8	4.77	.175	3.	6.
17	.058	.031	2.25	.5	5.8	11.6	4.87	.124	4.	8
16	.065	.037	2.625	.625	6.5	13.	6.02	.100	5.	10.
15	.072	.042	2.875	.625	7.2	14.4	6.09	.082	5.5	11.
14	.083	.058	3.375	.625	8.3	16.6	6.20	.061	7.	14
13	.095	.082	3.875	.75	9.5	19.	7.36	.052	8.5	17.
12	.109	.098	4.375	.75	10.9	21.8	7.50	.038	11.	22.
11	.120	.130	4.75	.75	12.	24.	7.60	.030	12.5	23.
10	.134	.149	5.25	.875	13.4	26.8	8.79	.025	14.	28.
9	.148	.200	5.875	.875	14.8	29.6	8.92	.022	15.	30.
8	.165	.232	6.5	1.	16.5	33	10.11	.017	19.	38.
7	.180	.295	7.125	1.	18.	36.	10.3	.014	23.	46.
6	.203	.379	7.75	1.25	20.3	40.6	12.7	.011	27.	54.
5	.220	.440	8.5	1.25	22.	44.	12.81	.009	30.	60.

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TABLE "B".

12	13	14	15	16	17	18	19	20
1.92	.5	1.	.644	.75	1.5	2.30	.5	1.0
1.54	.6	1.2	.520	1.00	2.	1.85	.6	1.2
1.27	.7	1.4	.431	1.50	3.	1.53	.7	1.4
.987	.8	1.6	.335	1.75	3.5	1.2	.8	1.6
.785	.95	1.9	.266	2.00	4.	.934	1.0	2.0
.603	1.25	2.5	.204	2.50	5.	.715	1.25	2.5
.475	1.5	3.	.123	3.50	7.	.434	1.5	3.0
.350	1.75	3.5	.118	3.75	7.5	.415	1.75	3.5
.267	2.25	4.5	.087	4.50	9.	.304	2.25	4.5
.187	2.75	5.5	.062	5.75	11.5	.218	2.75	5.5
.150	3.5	7.	.048	7.50	15.	.166	3.5	7.0
.119	4.	8.	.041	8.00	16.	.146	4.	8.0
.096	4.75	9.5	.035	10.0	20.0	.109	4.75	9.5
.068	6.	12.	.025	12.5	25.0	.084	6.	12.0
.057	7.75	15.5	.018	16.0	32.0	.063	7.75	15.5
.043	9.0	18.	.014	18.5	37.0	.048	9.0	18.0
.037	10.0	20.0	.011	21.0	42.0	.040	10.0	20.0
.028	11.0	22.0	.010	23.0	46.0	.036	11.0	22.0
.024	13.5	27.0	.008	28.0	56.0	.028	13.5	27.0
.019	16.0	32.0	.006	33.0	66.0	.022	16..0	32.0
.015	19.0	38.0	.005	240.0	80.0	.018	19.0	38.0
.013	21.0	42.0	.004	744.0	88.0	.014	21.0	42.0

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previously tabulated. As in Zingler's experiments, the wire was wound close and then pulled out to twice the close wound length. The author named quite a number of unfamiliar alloys such as "Eureka", "Kruppin", "Resista", and "Beacon". "Kruppin" seems to be very largely used in continental practice. It consists mostly of steel and its manufacturers claim that it can stand so large a temperature as 600°C without deterioration. For "Beacon" the highest specific resistance is claimed. The value is said to be 85.13 micro ohms per cu cm at 20° C.

In the Elec. World, December 31, 1887, Mr. W. A. Anthony advocated the use of low resistance wire for rheostats. His arguments would hardly stand in the light of present practice. While it is true, assuming the specific gravities of copper and German silver to be the same, that the surface exposed by the copper would be as much as that exposed by the German silver for an equal dissipation of watts, still we would have to draw the copper wire very fine, and would have to wind in layers for any length of consequence. The labor for winding such small wire is prohibitive and at present, when iron wire is predominant in the starting box field, it is evident that such considerations are of no consequence.

A good summary of alloy tests made by the German

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Reichenstaldt, is given by Appleyard in London Electric Review. The tests were made for the purpose of obtaining an alloy practically free from temperature effects, and which would have sufficient mechanical strength to enable it to be worked up into coils. The resistances were for scientific instruments of precision but we will only comment upon the comparatively cheap alloys tested. The following table gives values found for German silver and an alloy of copper and nickel which they term "Patent Nickel."

SUBSTANCE	Cu	Ni	Zn	Spec. Resis.	Temp. Coeff.	
German Silver,	60.16	14.03	25.37	30.	.00036	The specific
"Patent Nickel",	74.70	24.14		32.8	.00021	resistance is in micro-ohms per cu. cm. -

No comment is made upon the mechanical character of this patent nickel, but if it is of ordinary strength, it should readily come into the market for field rheostats, as its cost is about that of German silver and it is said to be less corrosive. The tests, which were very exhaustive and carried to an absurd accuracy, led the observers to assert that zinc is an objectionable metal in a resistance alloy for reasons of strength and ununiformity of temperature coefficient. That resistance alloys can be made with a negative temperature coefficient is shown by the patents of Weston on alloys for that purpose.

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The design of a starting box is mostly an empirical piece of work. After assuming the armature resistance to be expected, one has to assume a maximum current needed to bring the motor up to speed within a reasonable time. The maximum current is rarely over 50% above the normal full load current of the motor. The following design of a starting box is taken largely from Pochin who writes in the London Electrician, May 7, 1897. He states that there are few cases in which a motor will not start with normal current.

A shunt motor is selected whose input is 10 K. W. or 100 amps. at 100 volts, corresponding to a 8 1/2 K. W. motor. Then suppose we take the first button to give a value of 1/4 normal current or 25 amps. This means that the whole rheostat shall have four ohms resistance. Taking three steps to bring the current up to its normal value, we have values of current 0 - 25 - 50 - 75 - 100 amps. respectively, the fourth live botton giving the normal current. The above neglects armature resistance but we will assume the resistance of leads, brushes, and armatures as .1 ohms, which is ample. Taking a ten-step rheostat, the design leaves seven steps after normal current is reached. On the fifth step the current rises to 139 amps. momentarily, but the motor rapidly speeds up, reducing the current to 100 amps. again. The same proceeding

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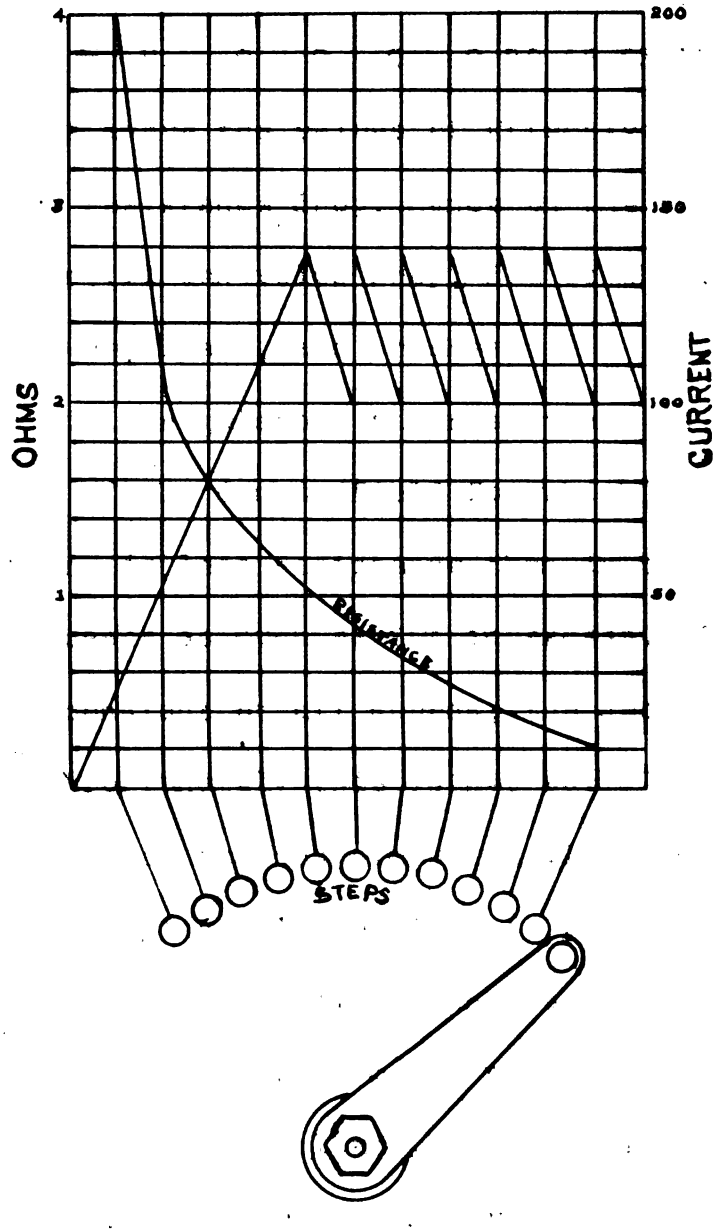
is gone through for the sixth step, and so on until the short circuit bottom is reached. In other words, 139 Amps. is the maximum current, or 39% above the normal. This assumes that the rheostat is given intelligent attendance, the whole ten steps being passed over in some fifteen seconds. The designer estimated that heavy inertia effect and careless handling would only produce a variation of from 120 to 160 Amps. instead of from 100 to 139 Amps. The resistance to each botton is selected as the ordinate of the logarithmic curve drawn in Diagram I. With uniform motion of the lever arm, this gives even impulses per button. Now we have two fixed points, (1) the fourth botton, (2) the tenth button, (when there is 0 resistance in the rheostat). Between these points we wish six points in geometric ratio. The author suggested laying a piece of paper along a slide rule from 1 to 11. Then take the paper and divide its length into six equal parts. Then again lay along the slide rule and read off the values at each division.

He claims that in a series motor the large selfinductance rounds off the steps.

The following table gives the design in full, while Diagram I shows the matter a little plainer.

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Contact,	1	2	3	4	5	6	7	8	9	10	11
Resistance,	4	2	1.33	1.	72	.52	.37	.27	.193	.139	.1 Ohms
Eff. E. M. F.	100	100	100	100	72	52	37	27	19.3	13.9	10 Volts
Motor C. E. M. F.,	0	0	0	0	28	48	63	73	80.7	86.1	90

In the above the values of Effective E. M. F. mean the volts lost in resistance drop, hence on the short circuit button there is still ten volts drop, due to the .1 ohm resistance of armature, leads, and brushes.

For field regulators the resistance is usually made equal to that of the dynamo field for which it is intended. Sometimes there is less resistance than in the fields, and in some rare cases as much as 25% in excess. If the armature current were constant at all speeds, the design would be simple, but unfortunately this is not so. The current taken at different speeds depends almost wholly upon the load that the motor is carrying. If the load is proportional to the speed, then the current will remain practically constant. Such a case is observed with motor pumps. Fan motors, on the other hand, do not give a load proportional to the speed, for the resistance of the air does not vary directly with velocity, consequently, for low speeds the current in the armature is less than at full speed. This can be seen from the consideration of the torque, which is directly proportional to the

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armature current, other things being equal.

Rheostats are often mounted on the same board as are the switches, and are sometimes interconnected with their controlling switches. At any rate, starting boxes of 5 H. P. or over should have a no-load and an overload release. The most common means of accomplishing this is to pass the shunt field current through a magnet near the rheostat arm's short circuit button. The arm of the rheostat has a piece of iron attached to it which acts as an armature to the magnet. Then when the motor is running smoothly, suppose, for instance the shunt field circuit is broken. Instantly, the magnet is demagnetized, releases the armature on the arm, and the arm flies back to its off position, being actuated by a strong spring coiled around the pivot of the arm. The overload release sometimes consists of an extra attachment to the no-load release above described, but is sometimes a species of independent circuit breaker. In the first case, the armature current passes through a magnet, which, when the current becomes excessive, raises a small iron armature, which, when raised, short circuits the field connection through the retaining magnet for the rheostat arm. Thus the retaining magnet is again demagnetized and the rheostat arm flies back to its off position.

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When the motor is shut down, especially if it be accomplished by use of the rheostat, a vicious spark results when the arm leaves the last live button. If the motor be a shunt and if a switch be pulled to shut down the motor, the inertia of the motor will cause a back current to flow from the armature through the fields until the speed is so greatly reduced that the field current is no longer sufficient to hold the arm against the retaining magnet. Evidently there will practically be no spark when leaving the last live button, because the voltage has become so low that the pressure of selfinduction will not be very great.

An ingenious magnetic blow out is in use by the General Electric Company. A small magnet is in series between the first and second live buttons. One end of this magnet has a horn which projects out to the dead buttons and thus would break any arc that followed the arm from the live buttons. Most starting boxes have more than one dead button in order to take up this arc and the extra precaution of this magnetic blowout is of doubtful necessity if the rheostat is in ordinary use.

The need of a rheostat which is entirely safe in ignorant hands is sometimes imperative, and to meet this demand the Ward Leonard Company make an excellent starting box,

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which is commonly dubbed the "fool proof rheostat." In addition to the no voltage release, this rheostat carries an auxiliary arm from the ends of which the current passes to the main arm. The arrangement can be better understood by reference to Diagram IV. This auxiliary arm slips into clips at each end, one blade being of iron, the other of carbon. The slips for the carbon project out a little further than do those for the iron blade. At the iron blade end, a solenoid in series with the motor armature actuates a plunger, which, when the current becomes excessive, raises into the magnet thereby tripping a catch which frees the auxiliary arm, which then flies out under the action of a spring, the carbon end of the auxiliary arm taking the spark. When the main arm is moved back to the off position, the auxiliary arm is forced into its clips and the catch again holds it in place. This arrangement prevents a careless attendant from moving the rheostat arm too fast, and thus causing an excessive current to pass through the motor armature and the rheostat.

In the above starting box an interesting principle is involved. It is evident that if the resistance material be imbedded in some substance which absorbs heat very rapidly and has a large heat capacity or specific heat, then quite a large current can be sent through the box, temporarily, the

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heat conducting material acting as an inertia effect similar to the inertia of masses. In the Ward Leonard rheostat this is accomplished by imbedding the resistance material, which is composition ribbon, in pure sand, whose specific heat is .195 (Kent). The whole is enclosed in an enamel-lined iron box with a slate cover, the junction being well sealed with putty. The sand prevents the access of air to the hot resistance material and the manufacturers claim that an extreme high temperature may be reached in the ribbon without any deterioration due to oxidation. The box is well and substantially made, is conservatively rated and the authors think that it is worthy of commendation.

The Ward Leonard "E" is the common iron clad made by that firm, consisting of an iron case containing enamel in which the resistance wire is zigzagged back and forth.

The Cutler-Hammer starting boxes are well made and their rating is good. The resistance wire is of pure soft wrought iron, tinned to prevent oxidation. These well known starting boxes have one notable feature, i. e., the resistance material being iron has an appreciable temperature coefficient. Ordinarily, the temperature coefficient of pure iron is about .00531, but about the heat of redness iron increases its resistance remarkably so one of these boxes can

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actually be short circuited across the line. Of course, in such a case the tin would be burned off and the wire would subsequently oxidize rapidly.

Instead of the connections of the shunt fields being made directly through the retaining magnet to the line terminal of the starting box, all of these starting boxes energize the fields with the first live button. This can be easily seen by reference to Diagram III. This always leaves the rheostat in series with the armature to take the energy of the field spark and consequently there is a very little arcing of the buttons when the rheostat opens, and the field insulation is not so apt to be punctured. When the rheostat is in its short circuit position, the armature of the retaining magnet makes connection between the rheostat arm and the frame of the retaining magnet, which is attached to the line lead of the retaining magnet. Then the field current passes from the line terminal through the arm and the retaining magnet to the shunt field terminal. For any intermediate position of the rheostat arm evidently the current has to "back up" from the rheostat arm to the first live button. This is no serious disadvantage, as the resistance of the starting box is very small compared to that of the shunt field.

The little starting box "G" of the General Incandes-

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cent & Arc Lamp Company is almost exactly like Cutler-Hammer "B", but is not so well made.

Two of the General Electric Company's starting boxes had their resistance material wound upon asbestos tubes; the other two had their windings placed upon asbestos tubes, which were then compressed into the shape of a slim "S". The compressed coils were then placed side by side, being insulated from each other by sheets of asbestos fiber. The whole is clamped together into a solid mass, a sheet of iron being interposed occasionally and projecting out about 3/4" to serve to conduct and radiate off the heat of the coils. This company uses German silver for its resistance material. It is high priced compared to iron, and the question arises, Why do they use it? In answer to this question they state that their experience has retained its use, but probably its employment serves as an inducement to purchasers, as a number ofconsumers are still very much prejudiced in favor of German silver. From all present indications, it is probable that iron will eventually replace German silver in starting box construction.

The little Wirt field rheostat is made completely iron enclosed. The resistance ribbon lies flat against the face, being insulated therefrom with thin sheets of mica. The back is

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then riveted down, it also being insulated from the winding by thin sheets of mica. This construction deserves attention. It was tested under severe conditions and we believe that if it be made air tight, it can sustain an enormous heat without injury.

The following is a brief description of each rheostat:

A -- Iron wire, tinned, on asbestos tubes, slate face, no voltage release, ten live buttons, one dead and one small auxiliary button.

B -- As above except only eight live buttons.

C -- German silver wire on asbestos tubes, slate face, twenty buttons.

D -- Iron clad, two rows staggered buttons, twenty-five buttons.

E -- Enamel iron clad, sixty buttons.

F -- Ribbon staggered and imbedded in sand, no load and overload release, slate front, nine live buttons, three dead buttons.

G -- As B.

H -- German silver ribbon on squeezed asbestos tubes, slate front, no voltage release, double arm and double rows of buttons, sixteen live and five dead buttons.

I -- German silver wire, no voltage release, eight

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live and three dead buttons.

J -- Similar to I.

K -- Similar to H.

L -- Iron clad, twenty-five buttons.

The kodak views give the general appearance of the rheostats and their ratings are given just above Table I below.

The rheostats were all subjected to resistance tests between buttons and also for insulation resistance. These tests were at the common temperature of a room and were performed with a D'Arsonval Galvanometer and an Anthony bridge. The lead wires were of negligible resistance, their resistance being .0016 Ω. "A" was the only rheostat affected in the fourth place, so allowance was made in its results. The results are embodied in Table I below. In some cases the wires from the coils to the buttons were not connected as well as they should have been. This accounts for some minor signs in the table. Discrepancies were carefully checked. Where the joints could be gotten at, they were soldered when they showed high resistance due to poor contact. "G" had a very bad connection to one of its leads.

We next went about finding the temperature coefficient of the resistance material in rheostats. The apparatus used is shown in Fig. III. It consisted of a double-walled pine

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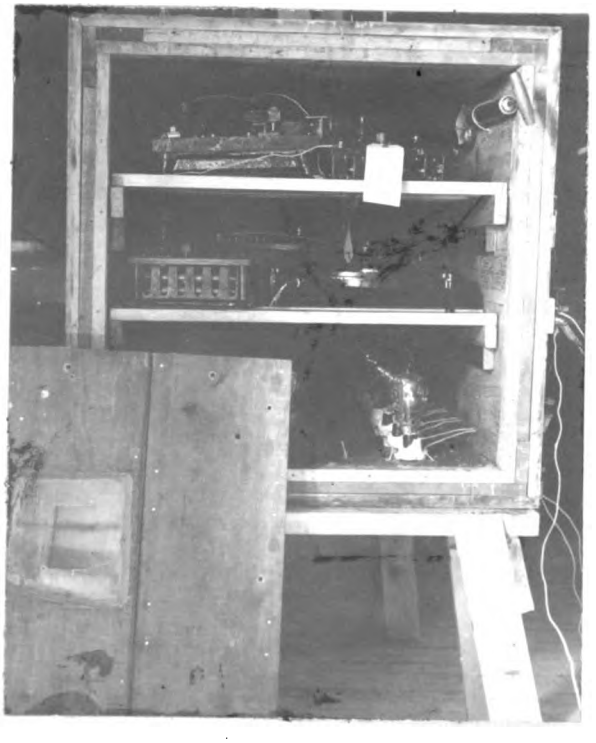
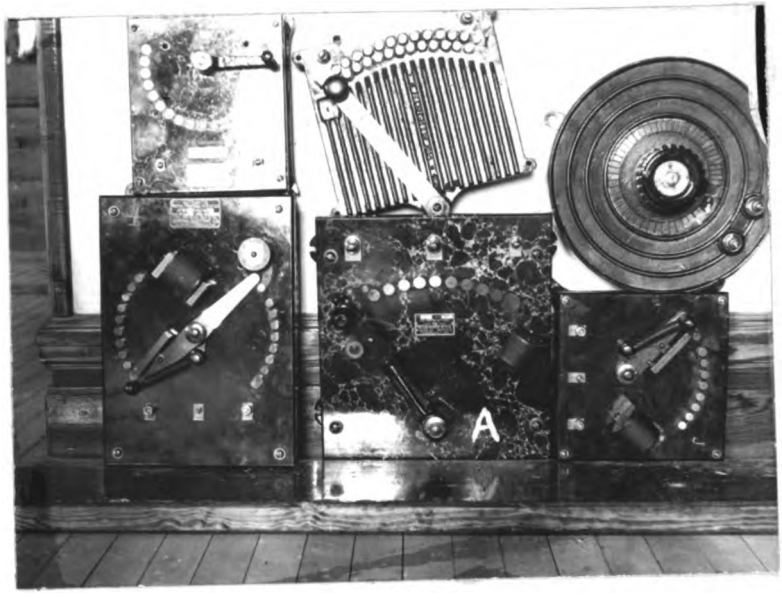
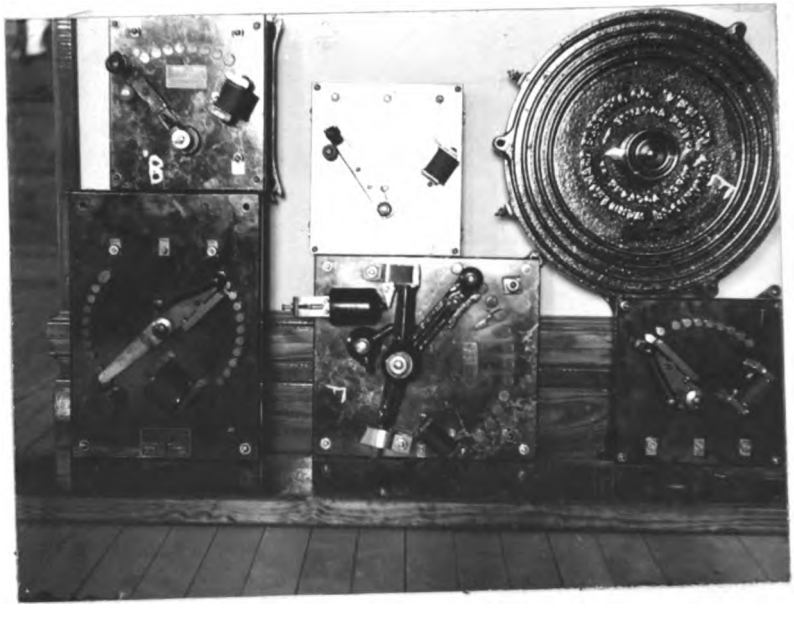


Fig. 1.

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HEADINGS FOR TABLE I.

A	Cutler Hammer,	5 H. P. 115 Volts - Starting Box.
B	" "	5 H. P. 230 " " "
C	" "	.4 Amp. 800 Ohm Field Rheostat.
D	" "	.78 " " "
E	Ward Leonard,	5-10 Amp. 12.5 Ohm, 125 Volts Field Rheostat.
F	" "	7 1/2 H. P. 125 Volts, Starting Box.
G	Chicago Rheostat Co.,	1 H. P. 110 Volts, Starting Box.
H	General Electric Co.,	7-10 H. P. .500 Volts " "
I	" " "	3/4-1 H. P. 250 " " "
J	" " "	1 H. P. 200 " " "
K	" " "	10 H. P. 500 " " "
L	Wirt Electric Co.,	2 Amp. 30 Ohm Field Rheostat.

For connections see Figs. II, III and IV. The connections for Cuttler-Hammer "A" and "B", and G. and I's "G" are exactly similar to those shown in Diagram II.

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TABLE I.

Temp. 23° Cen.

READ-ING.	Res. per Coil. A	Res. per Coil. B	Res. per Coil. C	Res. per Coil. D	Res. per Coil. E	Res. per Coil. F
1	.539	2.705	14.36	3.034	.3475	.1420
2	.486	1.610	18.53	2.83	.0525	.1820
3	.308	1.205	12.64	3.116	.1810	.1800
4	.159	1.196	13.5	2.990	.1475	.1850
5	.146	.698	18.68	5.580	.1885	.1850
6	.120	.660	15.12	5.710	.1780	.1860
7	.122	.454	20.73	5.790	.1460	.1840
		TOTAL				
8	.112	8.36	28.20	5.770	.1440	.3510
						TOTAL
9	.110		18.90	5.850	.2550	1.48
	TOTAL					
10	2.101		38.5	5.980	.0800	
11			41.45	6.000	.1650	
12			70.9	6.320	.7670	
13			68.3	5.720	20.20	
14			67.7	6.250	-21.32	
15			74.7	6.010	-.246	
16			70.4	8.510	.1490	
17			64.2	8.390	.1650	
18			57.4	11.39	.1650	
			TOTAL			
19			712.5	11.20	.1640	
20				14.16	.1740	
21.				15.34	.1530	
22				16.3	.1780	
23				14.8	.1410	
24				15.1	.2250	
25				14.72	.1650	
				TOTAL		
26				205.6	.2550	
27					.1750	
28					.3950	

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READ-ING.	Res. per Coil. E
29	.214
30	.211
31	.215
32	.320
33	.120
34	.190
35	.210
36	.230
37	.245
38	.140
39	.260
40	.262
41	.253
42	.260
43	.395
44	.120
45	.255
46	.290
47	.280
48	.290
49	.285
50	.310
51	.383
52	.310
53	.283
54	.290
55	.330
56	.635
57	000
58	.315
59	.320
60	.315
61	3.540
Total, -	16.550

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Res. per Coil. G	Res. per Coil. H	Res. per Coil. I	Res. per Coil. J	Res. per Coil. K	Res. per Coil. L
1.475	.0595	1.073	2.420	.0595	.60
1.300	1.0415	4.830	3.204	.9745	.53
1.390	1.0850	10.826	2.990	1.001	.60
1.400	1.0080	10.91	4.896	1.135	1.14
2.480	1.0240	14.83	10.75	.835	.16
1.465	1.5120	20.15	20.18	1.508	.31
2.560	1.5480	19.83	20.06	1.457	1.75
TOTAL		TOTAL	TOTAL		
11.97	1.2220	82.4	64.4	1.477	0
	3.3750			1.528	1.22
	2.9100			1.553	-.03
	3.0200			1.502	9.75
	2.9650			2.92	-8.18
	4.03			2.99	.42
	4.09			3.03	.54
	TOTAL				
	28.8			3.00	.42
				Total: 24.74	.02
					.85
					1.15
					.96
					0
					1.14
					.42
					.80
					.62
					TOTAL
					27.7

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box in which shelves were arranged for the reception of the rheostats. The connections were run out through the holes, which were chinked with cotton waste and putty. The box was heated by some twenty 16 cp. incandescent lamps, which were arranged for convenient control. For the finer gradations, a field rheostat was used in series with a variable number of lamps. The cover was made double thickness and was joined with putty. A double glass window was provided through which to see the thermometer. In order to obtain a uniform termperature throughout the box, a stirring apparatus was inserted consisting of a bicycle foot pump with the end knocked off. The handle was run through a suitable stuffing box in the cover. The circulation was thus accomplished by shooting a stream of air out from the pump. The whole apparatus worked extremely satisfactorily, allowing of easy regulation of temperature and not requiring constant attendance in order to keep the temperature steady. Our range of work was from 25°C to 85°C. We could easily have gone higher but for the danger to the compounds used on the faces of the rheostats, such as handles to rheostat arms.

Lead wire resistances were practically negligible. The following gives values for three pairs:

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J	.014	at 23°C.
A	.009	" "
L	.011	" "
Avgr.	.0113	" "

All the lead wires were of the same gauge and of practically the same length, so the average value is assumed for all. The resistance was only allowed for in "A", as it was the only rheostat affected by such small resistance.

Table II shows the results, which are better understood by reference to the curves. Only A, B and G had appreciable temperature coefficients. Their temperature coefficients as calculated from our data are

A	.00382	from 25°C to 85°C.	
B	.00660	" " " "	Average, .00452
G	.00314	" " " "	

It was our intention to pass currents through the rheostats and measure their rise in temperature by means of their rise in resistance, but the temperature coefficient was not large enough to allow of this method, so we were left without any truly accurate method of testing the starting boxes.

In the small table just under Table II is given a check of the negligible temperature coefficients of rheostats K and J. It is seen that from 27°C to 89°C they change a very small amount in resistance. The test was made by heating coils from K and J in an oil bath and measuring their resistance by the Wheatstone bridge method.

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TABLE II.

Data For Temperature Coefficient.

Temp. Cen.	A	B	C	D	E	F	G
25°	2.08	8.36	712.5	205.6	16.55	1.480	11.97
35	2.145	8.71	714.3	205.6	16.57	1.473	12.63
45	2.214	9.16	716.4	205.6	16.63	1.480	13.17
55	2.290	9.614	718.6	205.6	16.66	1.481	13.61
65	2.364	9.99	720.4	205.8	16.70	1.492	14.23
75	2.457	10.38	722.2	205.8	16.74	1.507	14.66
85	2.514	11.06	724.	205.8	16.74	1.515	14.93

Temp. Cen.	H	I	J	K	L
25°	28.8	82.4	64.4	24.74	27.70
35	28.8	82.6	64.6	24.94	27.68
45	28.91	83.00	64.8	25.03	27.71
55	29.01	83.26	64.96	25.09	27.73
65	29.10	83.50	65.20	25.19	27.64
75	29.20	83.50	65.34	25.29	27.48
85	29.29	83.56	65.2	25.14	27.33

Checks By Boiling in Oil.

Temp. Cen.	Coil From K.	Coil From
27°	1.04	19.88
89	1.06	20.24

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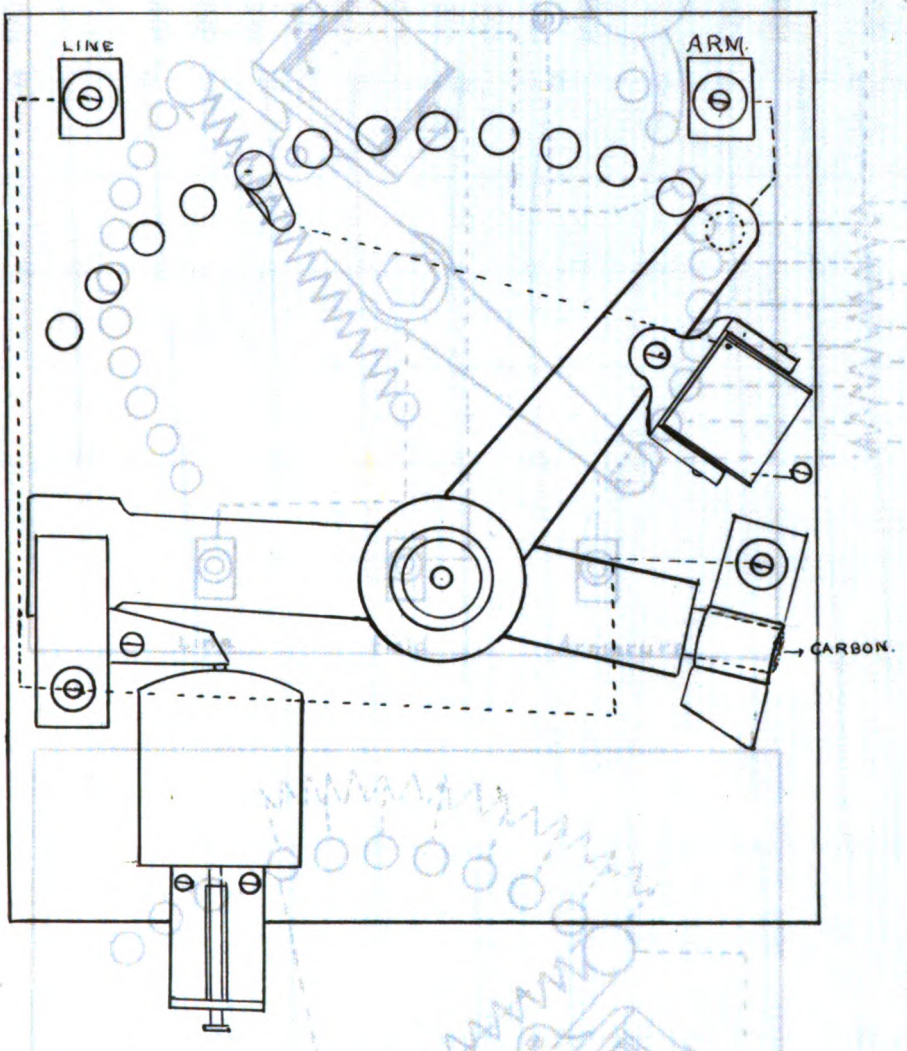


Diagram No.1.

WARD LEONARD.

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Diagram No.1.

WARD LEONARD.

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General Electric Co

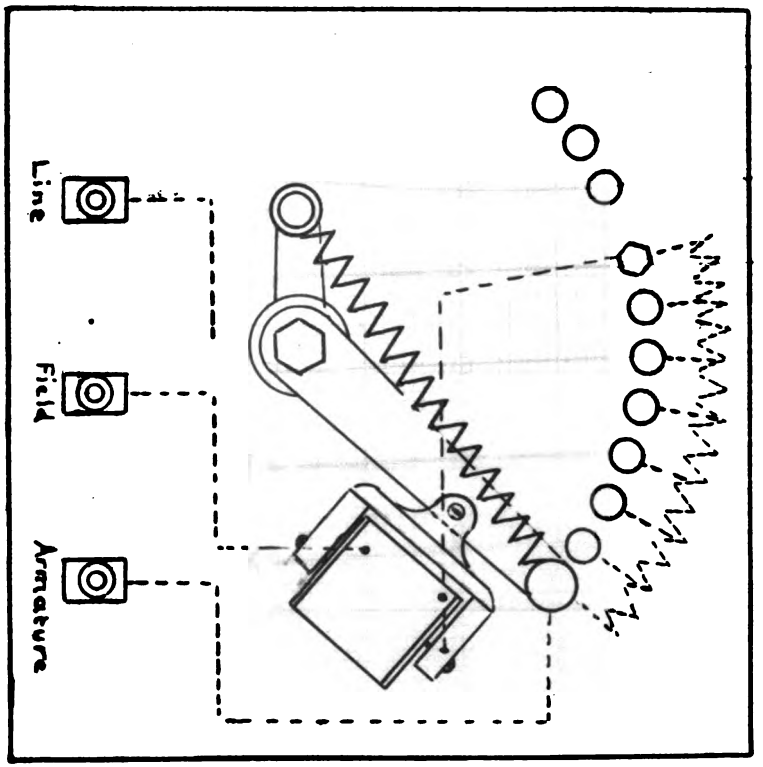


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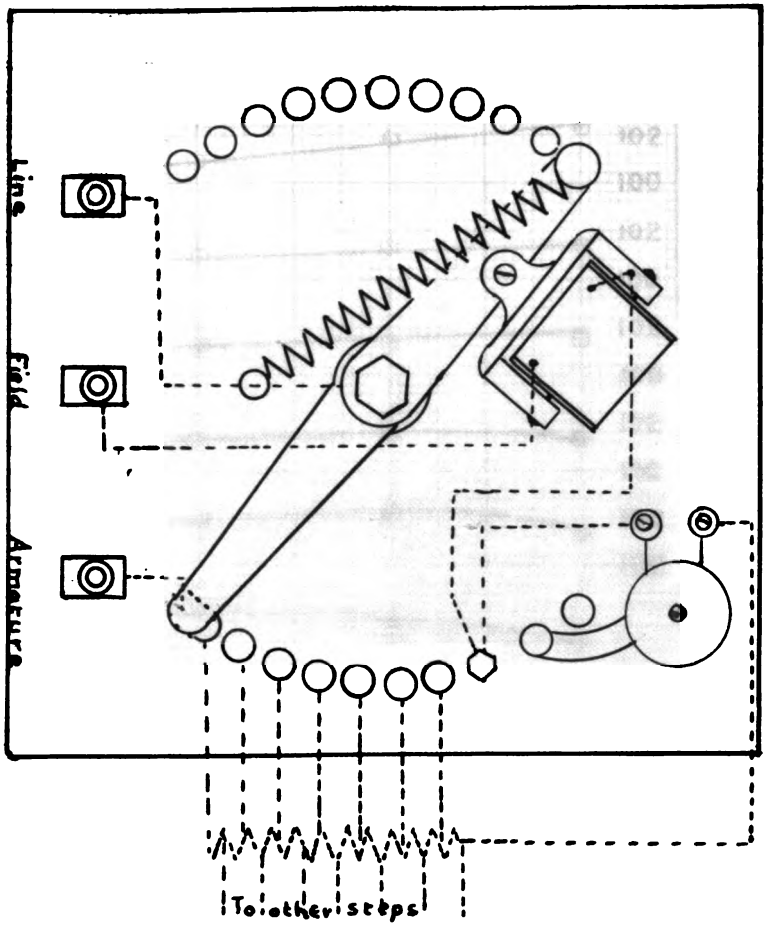
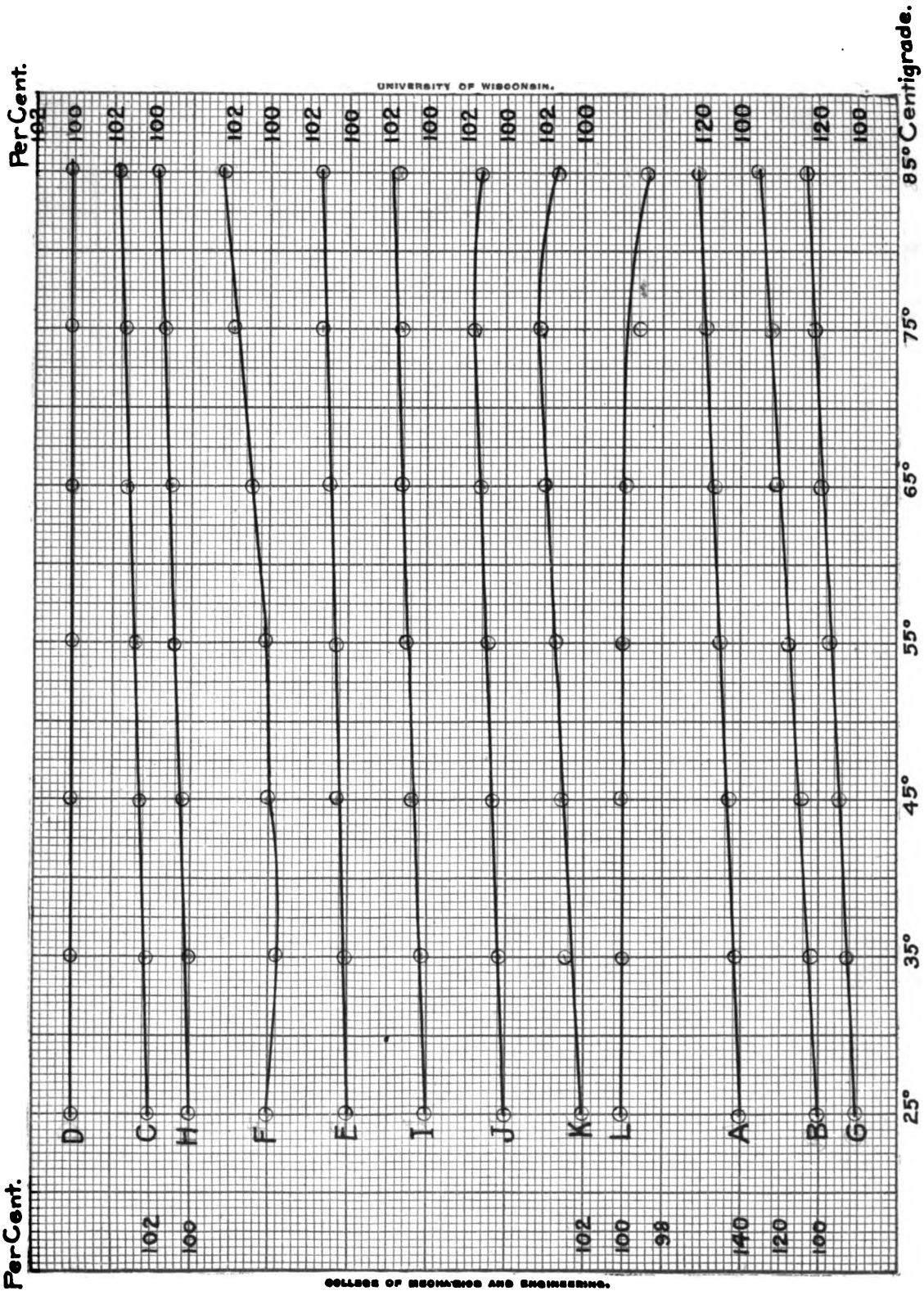


Diagram No. 3.

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GENERAL ELECTRIC CO

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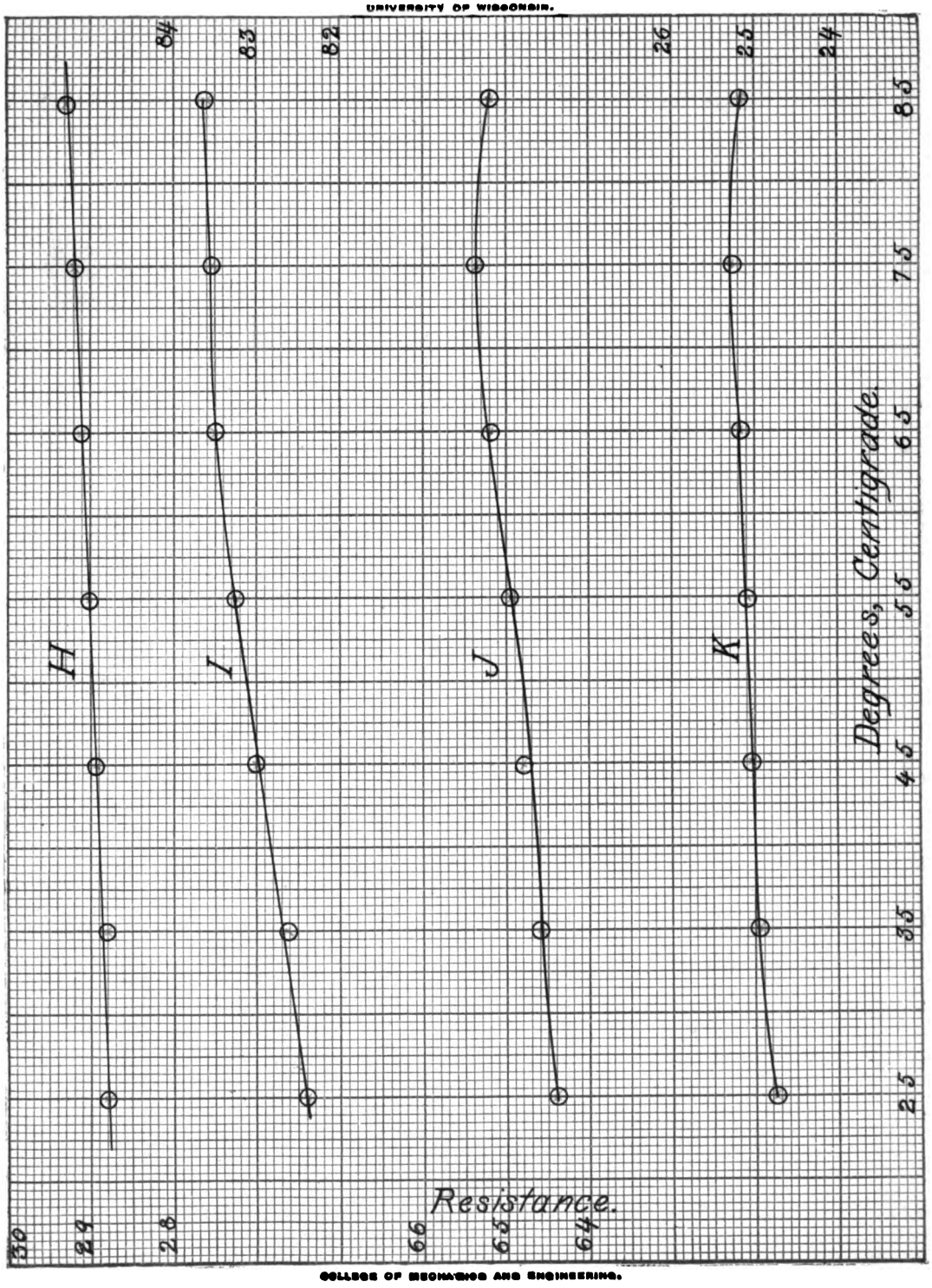


Resistance in % with Resistances at 25°C. as 100 %.

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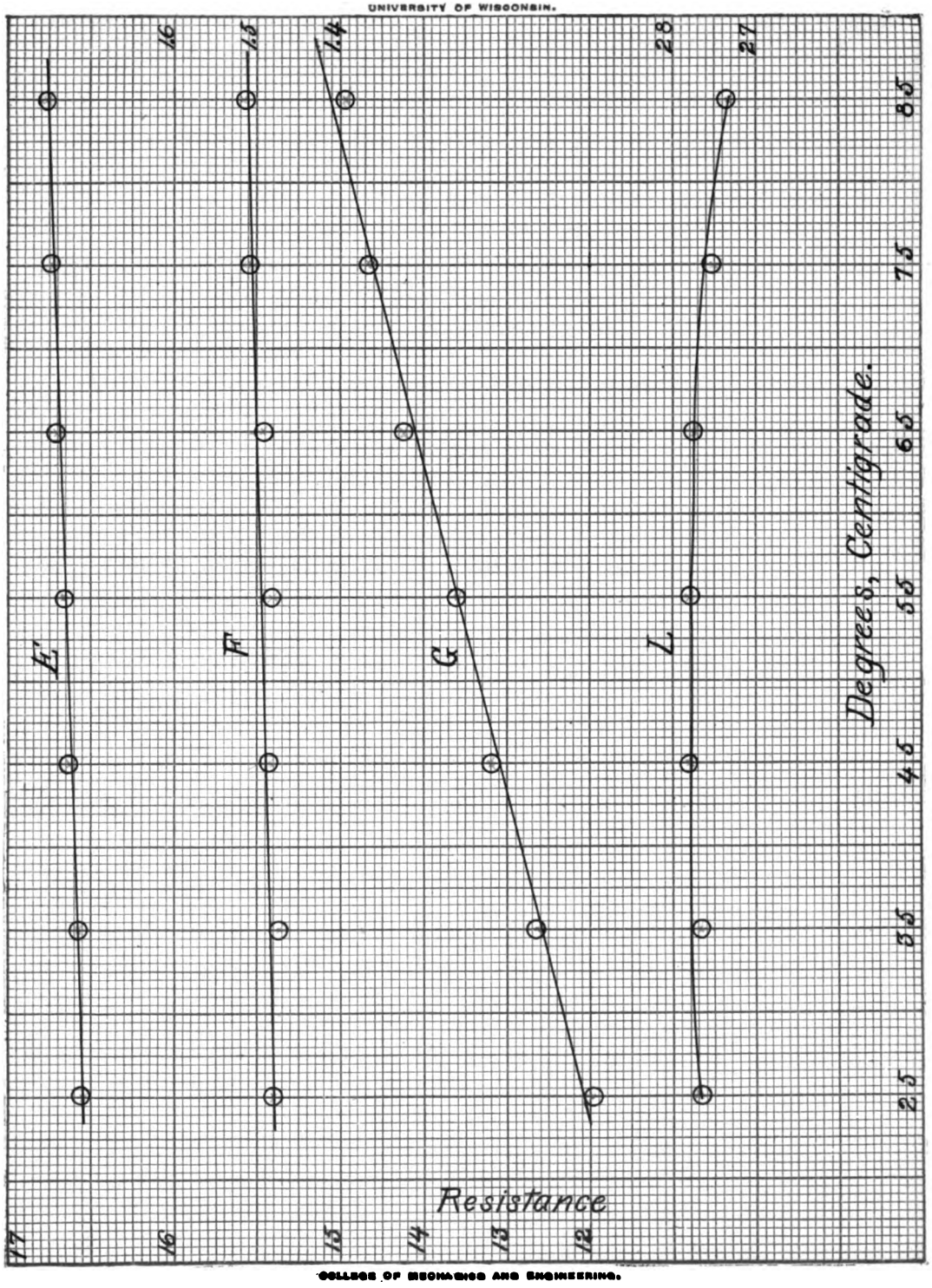


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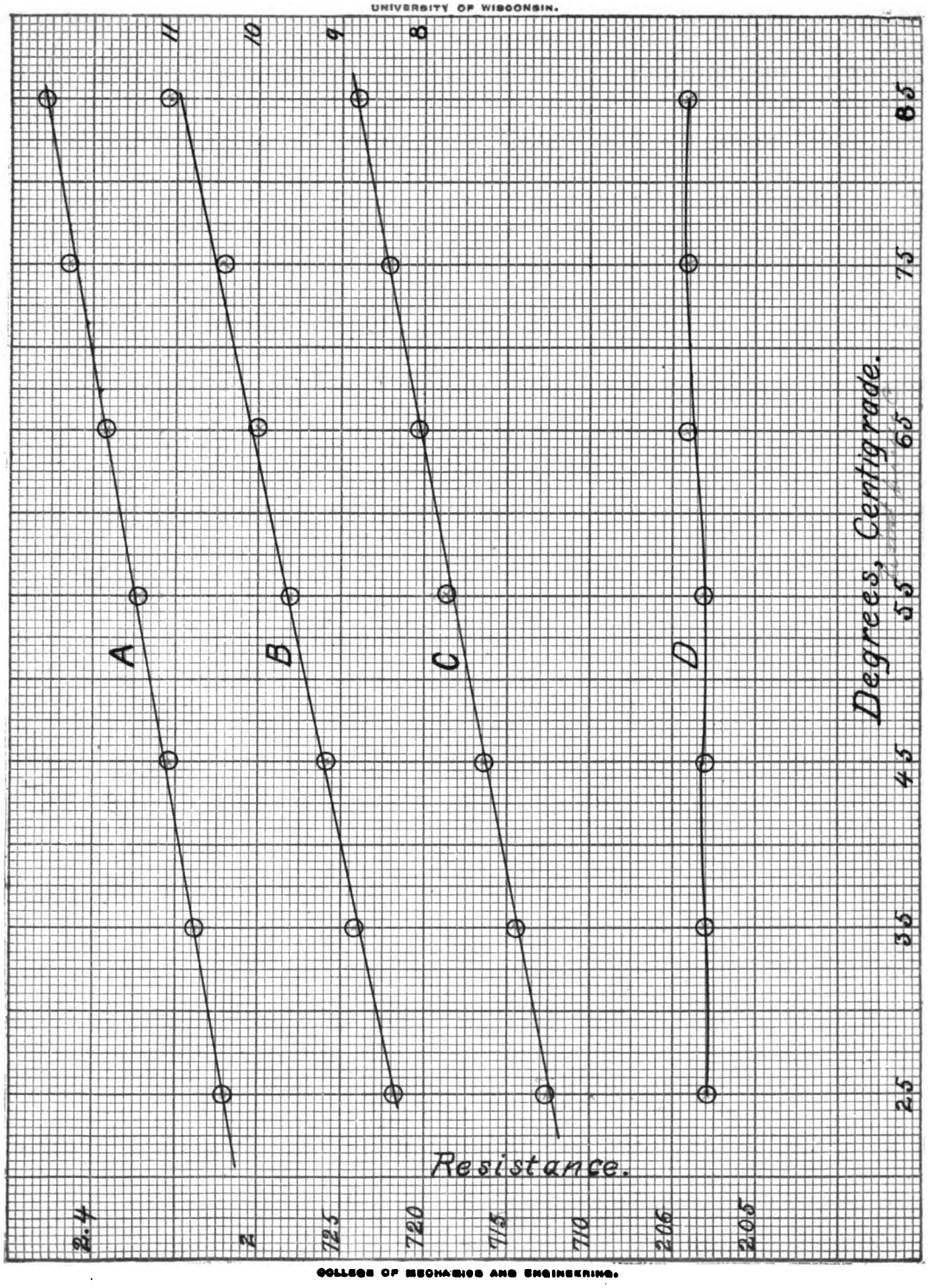
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The tests for the temperature coefficients were very carefully made. At least four hours were allowed for the rheostats to assume a constant temperature throughout. We took A as a standard, for it was very large and we knew that it had a comparatively large coefficient of temperature. While waiting for the boxes to come to a common temperature, we took readings of A occasionally until it came to a constant resistance, thus showing that it had reached a constant temperature.

Insulation tests were taken in connection with the above temperature coefficient test. The results are given in Table III. All of the rheostats showed good insulation tests and the figures of the table are only approximate, as the bridge would only indicate within some 50%.

Tests upon the carrying capacity of the rheostats were next made. With the starting boxes it was found that a current could be carried continuously the value of which was one-fourth of the full load current of the motor for which the starting box was designed. On this basis results in Table IV can be better compared. The current was passed through until the thermometers came to a steady temperature. Putty and waste were used upon the thermometer bulbs to prevent external radiation. The seventh column tells whether the thermometers were directly upon the resistance wire, or upon the exterior

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TABLE III.

Rheostat	Temp. C°	Insulation Resistance Megohms	Temp. C°	Insulation Resistance Megohms	Temp. C°	Insulation Resistance Megohms
A	25	19	45	10	75	10
B	25	90	45	10	75	10
C	25	50	45	10	75	10
D	25	50	45	10	75	10
E	25	50	45	10	75	10
F	25	40	45	10	75	4
G	25	40	45	10	75	4
H	25	100	45	10	75	10
I	25	60	45	10	75	10
J	25	60	45	10	75	10
K	25	50	45	10	75	10
L	25	19	45	10	75	10

Insulation from dead buttonsto live buttons practically infinite.--

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TABLE IV.

Rheostat	Current	Time Min.	Cen.° Temp. Last Coil	Cen.° Temp. First Coil	Cen.° Room Temp.	Therm. was	Volts at Start	Volts End
A	5	60	41.5	93.5	24	On Coil	10.6	12.6
B	3	60	50	100	23	On Coil	25.1	28
C	2.75	60	34	93	22.5	Outside	108.8	108.8
D	.8	60	59	65.5	22.5	Outside	117#	117#
E	3	60	55.5	70.5	18	Outside	50	50
F	11	90	71	75	18	Outside	16.5	16.5
G	1.5	60	37	45.5	22.5	On Coil	18.5	20.5
H	3.5	60	115	131	22.5	On Coil	93.5	94.4
I	.75	20	30.50	80.5	22	On Coil	63	63
J	1	20	40	134	22.5	On Coil	63	64
K	3.25	20	46.5	80	22.5	On Coil	69	69
L	4	60	115	156.5	18	On Coil	113	111

Over part of Coils.-

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case, as was necessary with iron clads. The field rheostats had approximately their normal current sent through them with the exception of L, which had some 50% overload. It may be noted that starting boxes A, B and G increased their resistance very materially, as may be seen from columns eight and nine.

The releases of the rheostats were next tested. The Ward Leonard overload circuit breaker worked splendidly, breaking over 100 amperes without any severe sparking at the contacts. All of the no voltage releases appeared to be too retentive. A current as small as .05 amperes would just hold the rheostat arms. A small jar would free the arm and allow it to fly back, but the authors think that this feature should really receive attention. The magnets were all of soft iron and could hardly have a large retentivity of magnetism. Of course there is no magnet which can be instantly demagnetized save by a reversal of the current. Just where in the stopping of the motor the no voltage release should act is a subject of considerable importance. Evidently the retaining magnet must be strong enough to resist all jars while the motor it controls is in normal operation, and it must be likewise strong enough so as not to release the lever arm before the armature current has diminished sufficiently so that the contacts will not be severely injured. Since the retentivity of magnetism

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helps out in holding the lever until the voltage has dropped to a proper value, this problem is not serious. A practical specification for such a device could read: "It shall not break above two-thirds normal voltage, nor shall it retain until one-half normal voltage is reached." We really want the magnet to retain the arm until just before themotor C. E. M. F. has dropped to such a value that a sudden return of the full line voltage would injure the motor.

The same principle of the retentivity of magnetism also deserves attention in the overload releases previously described, where a magnet in series with the motor armature raises an armature which, when raised, short circuits the field circuit through the retaining magnet. Suppose a heavy current flows, the overload release works but some time is consumed in allowing for the demagnetizationof the retaining magnet. Obviously, this release may be classed as a mean between the fuse, which blows by accumulated heat, and the magnetic circuit breaker, which acts instantaneously. Many people have expressed opinions on this interesting overload release. We really believe it to be a very desirable adjunct, especially when the group of circuits, of which the motor circuit constitutes one, is protected by a large magnetic circuit breaker, and the motor itself is protected by carefully selected

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TABLE V.

CUTLER HAMMER COIL BURNED OUT.--

Volts	Amperes	Resistance
4	2.5	1.6
18	9.6	1.88
33	10.7	3.08
39.5	9.5	4.16
48	8.2	5.85 (Red Hot)
50	7.5	6.67
52	7.1	7.3
52	6.8	7.65
79.5	8.2	9.7
112.5	10.0	11.25
145	11.5	12.6 (Fused)

General Electric Coil.-- Red Heat.

27.5	1.5	18.3
42	2.3	18.3
50	2.75	18.3
59	3.2	18.3
62	3.4	18.3

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fuses. Then for an immense instantaneous current the magnetic circuit breaker could be relied upon. For a small overload for a long time, the fuses would protect the motor. Between the two protections, acting as a check upon both, is the overload release, which acts as a slow circuit breaker but which is quicker in acting than is the fuse.

The ammeters and voltmeters used in the test were calibrated with a Kelvin balance. The instruments were new and of Weston make, having very little error.

As a final test we took a coil from G. E. Co.'s rheostat J and one from Cutler-Hammer Co.'s "B". We wished to see if the temperature coefficient would vary as red heat was reached. The results can be seen in Table V. At red reat the rheostat coil from J showed no change in resistance, the increase being marked just at red heat. So large was this change that in B it took 147 volts to fuse this one coil. Thus either A or B, which were intended for 110 volts, could be short circuited across the line without other injury than the burning of the tin upon the iron resistance wires. In either of the above cases the windings stayed tight upon the tube upon which they were placed.

The choice of a rheostat for any particular work should have careful consideration. There are some points which

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are essential in all rheostats, regardless of what use they are to be put to, except in rare cases of temporary rheostats. All parts that are soldered should be away from the heated parts; so if the wire be used as a resistance, its joints should be made away from the main body of the resistance, and the joint should be favorably situated for the dissipation of heat, i. e., should be near the iron case or wholly exposed to the air. A good plan is to braze all joints, as is done in the case of the Cutler-Hammer Company. The Wirt Company uses no solder, its resistance material being one long ribbon or wire without joints, the connections to its buttons being made by direct contact. This rheostat (L) also has an advantage in the fact that it is extremely compact and has no projecting parts to get broken save two binding posts. Where hard service is required, the rheostat or starting box must be made so that occasional transportation is not likely to injure it by breakage.

It is advisable to have little rubber or composition that melts or softens at a comparatively low temperature. The G. E. Co. make their rheostat handles of some composition, which softened quite a deal during our temperature coefficient test. Our highest temperature was 85°C. Still it is safe to say that under common circumstances the temperature of the handle would never become as high as 85°C, so really this is not a

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bad construction, for the composition is an excellent insulator and is very neat in appearance.

For any particular service the companies make controllers adapted thereto, so it is out of the question to outline thoroughly the choice of rheostats for all classes of service. For elevators, printing presses, etc., thoroughly constructed rheostats are put on the market by several well-known firms and a choice can be made from catalogue, remembering the general construction employed by the manufacturer in question, and the consideration he gives to various points mentioned in this paper. For use in wet places or places subject to chemical fumes, we would recommend starting rheostats similar to F or H, though preferably like F. Under the same circumstances, the field rheostats D, E or L would give good service. For every day use under normal circumstances any of the previously mentioned starting boxes would answer, but rheostats such as A or I would be preferable on account of cost.

In conclusion we will remark that the rheostat of today is in a very good stage of development. The prices are reasonable and are far below their former values. We believe that improvements in the near future will mostly be in the line of better and more reliable overload releases, and possibly the substitution, where possible, of buttons which are easily re-

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placeable from the front of the rheostats.

DATA OF RELEASE MAGNETS.

Resistance.	Name of Magnet.	Energy Normally Consumed. Watts.	Rheostat.
1.36	Shunt Coil	1.36	A
11.00	" "	.66	B
.80	" "	1.80	F
11.50	" "	1.90	G
9.20	" "	1.58	H
15.40	" "	1.35	I
15.10	" "	.90	J
9.80	" "	1.58	K
.00168	Overload Release	3.00	F

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